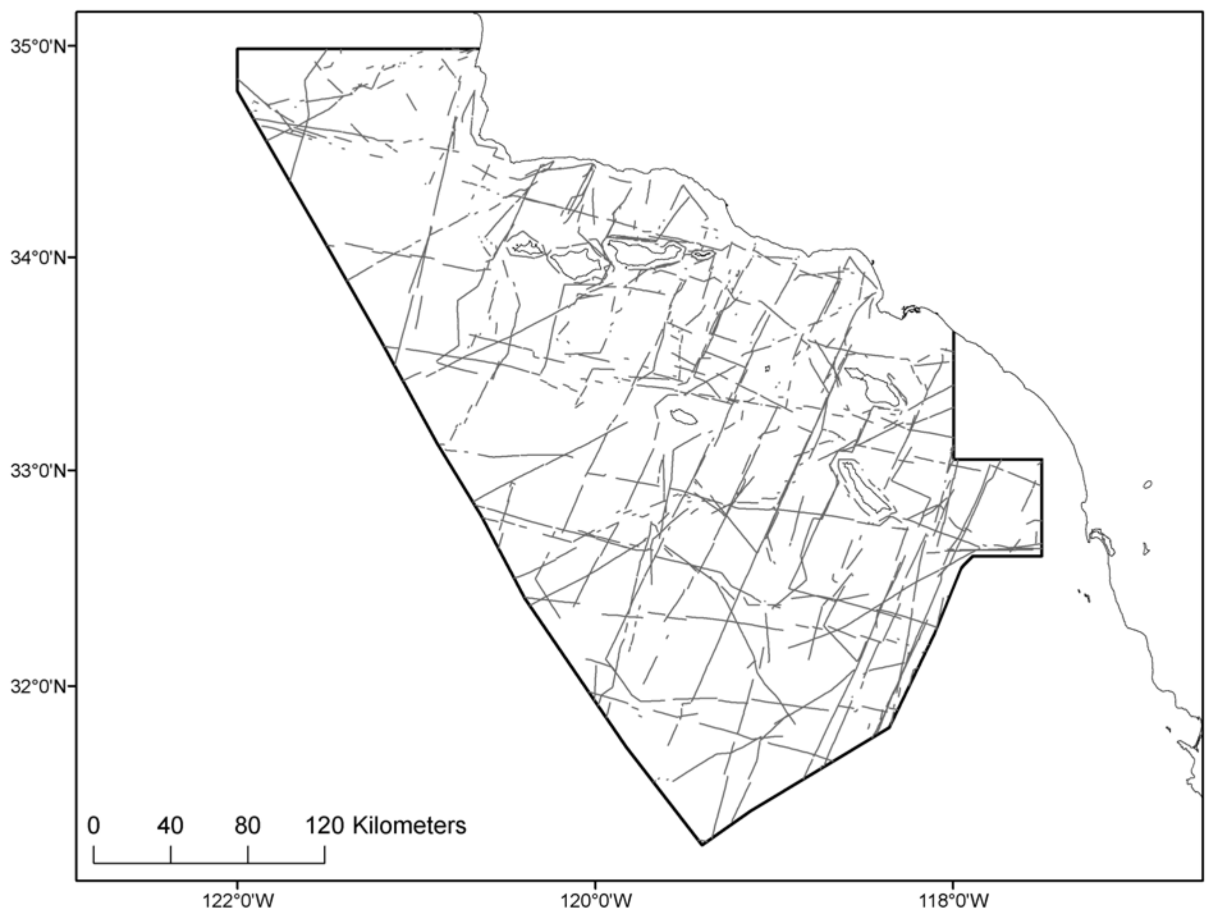
Mitigating the risk of large whale ship strikes in the Southern California Bight

J. V. Redfern[1*], M. F. McKenna[2], T. J. Moore[1], J. Calambokidis[3], M. L. DeAngelis[4], E. A. Becker[5], J. Barlow[1], K. A. Forney[6], P. C. Fiedler[1], S. J. Chivers[1]

We estimate the risk of large whale ship strikes in eight alternative shipping routes through the Bight. We used spatially referenced whale and oceanographic data that were collected by the NMFS's Southwest Fisheries Science Center on two comparable NOAA research vessels from August through November in 1991, 1993, 1996, 2001, 2005, 2008, and 2009 (Fig. 1). Whale data were collected during daylight hours using line-transect methods (Buckland et al. 2001); field protocols are described in detail by Kinzey et al. (2000) and Barlow and Forney (2007). Transects were divided into approximately 5km segments of continuous survey effort.

Figure 1. Transect surveyed by the NMFS's Southwest Fisheries Science Center on two comparable NOAA research vessels from August through November in 1991, 1993, 1996, 2001, 2005, 2008, and 2009.



Three species were included in our analyses: fin (*Balaenoptera physalus*), blue (*Balaenoptera musculus*), and humpback (*Megaptera Novaeangliae*) whales. Sample sizes are shown in Table 1. For each species, generalized additive models (GAM) were used to relate the number of whales in each 5km segment to sea surface temperature (SST), sea surface salinity (SSS), the natural logarithm of surface chlorophyll concentration (LNSC), mixed layer depth (MLD), and distance to the 200m isobath (isobath). For the isobath variable, distances in waters shallower than 200m were multiplied by negative one. The distance traveled on effort in each segment was incorporated as an offset in the models because the amount of effort varies somewhat between segments. The software package S+ (Version 8.1 for Windows, Tibco Software Inc., 2008) was used to fit the GAMs; we chose cubic smoothing splines (Hastie and Tibshirani 1990) with a maximum of three degrees of freedom for all predictor variables to capture non-linear relationships, while limiting the inclusion of unrealistic detail in the shape of the function (Forney 2000).

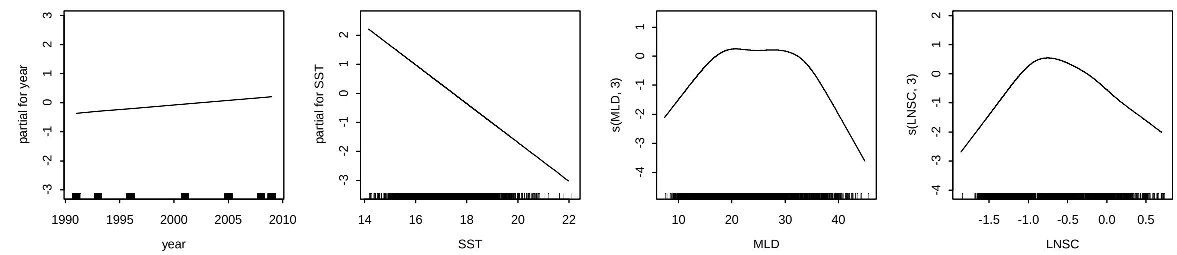
Table 1. Number of sightings and number of individuals are summarized for the three species considered in our analyses.

	Fin Whales		Blue Whales		Humpback Whales		
	Number of sightings	Number of individuals	Number of sightings	Number of individuals	Number of sightings	Number of individuals	Total number of segments
1991	12	21.96	16	33.58	3	6.33	330
1993	4	6.00	20	32.16	1	2.13	165
1996	24	34.87	24	37.50	1	1.75	205
2001	3	32.50	2	4.33	2	4.00	210
2005	6	11.75	4	7.20	1	3.00	157
2008	15	37.43	0	0.00	6	11.50	178
2009	53	105.51	22	34.46	17	32.61	833
All years	117	250.02	88	149.23	31	61.32	2078

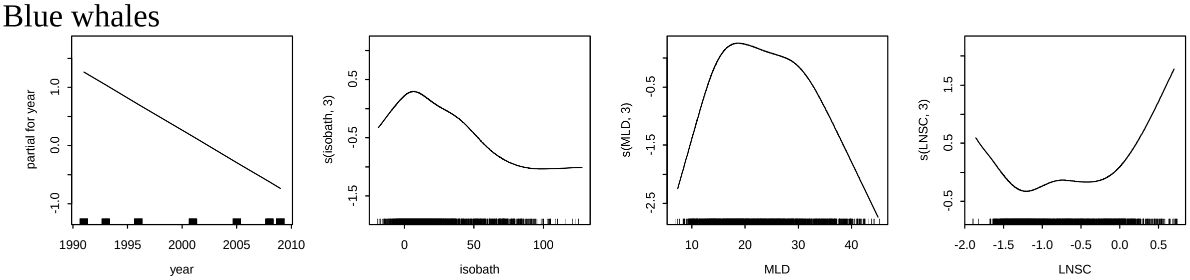
We fit Poisson GAMs in which overdispersion was corrected using a quasilikelihood model. An automated forward/backward stepwise approach based on Akaike's Information Criterion (AIC) was used to select the variables for inclusion in each model as well as the degrees of freedom for the cubic smoothing splines (Ferguson et al. 2006; Becker et al. 2010). Each model was fit three times, starting with a null model that included only the intercept. The dispersion parameter from the null model was used to calculate AIC values in the algorithm *step.gam*, which tested all predictor variables for inclusion in the second model as cubic smoothing splines with two or three degrees of freedom. For the third model, the dispersion parameter from the second model was used to calculate the AIC values in the algorithm *step.gam*, which tested all predictor variables for inclusion as linear terms or cubic smoothing splines with two or three degrees of freedom. Finally, we included a linear fit to year to account for changes in whale abundance during this time period. Models for each species are shown in Figure 2.

Figure 2. Results of the generalized additive models used to relate the number of whales to oceanographic and bathymetry variables.

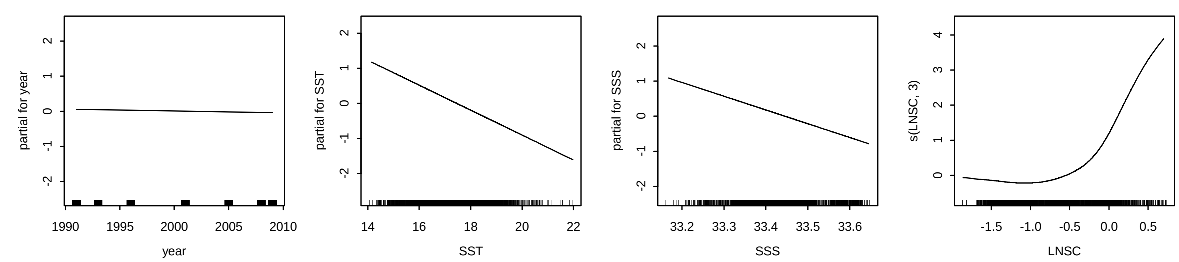
Fin whales



Blue whales



Humpback whales



These models explain 17% of the deviance for fin whales, 14.9% for blue whales, and 31.2% for humpback whales. Ratios of observed to predicted number of individuals are shown in Table 2. The percentage of explained deviance for fin and blue whales is higher than encounter rate models built for these species using data from the entire US west coast (Becker et al. 2010) and the standard deviation of the ratios is lower (Barlow et al. 2009); hence, the models built just for the Bight perform as well as models built for the entire US west coast. The percentage of explained deviance for humpback whales was similar to encounter rate models built for this species using data from the entire US west coast (Becker et al. 2010), but the standard deviation of the ratios was much higher (Barlow et al. 2009). This decrease in performance may have occurred because our study area represents the southern edge of humpback whale distributions on the west coast and sample sizes were much smaller for this species.

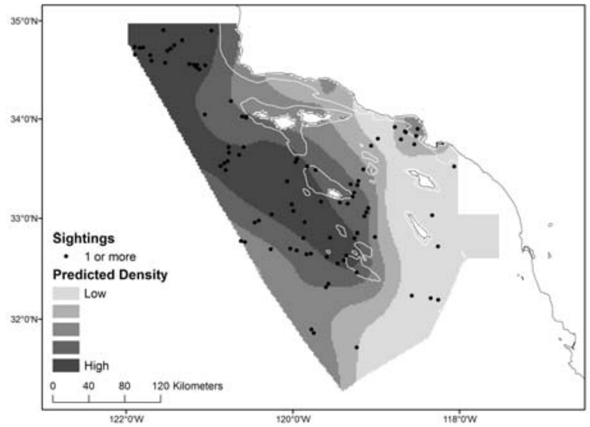
Table 2. Ratios of observed to predicted number of individuals are shown for each year. The ratios for all years combined are one for all species indicating that the predicted number of whales is the same as the observed number of whales when the entire study area is considered. Ratios for individual years indicate the variability in the predictive power at fine temporal scales. Note that no blue whales were observed in the study area in 2008.

	Fin	Blue	Humpbacks
1991	0.926	0.698	1.525
1993	1.226	1.462	2.100
1996	1.031	1.458	0.434
2001	1.162	0.451	2.266
2005	0.540	0.859	0.186
2008	1.034	0.000	2.700
2009	1.037	1.214	1.087
All	1.000	1.000	1.000
SD	0.223	0.419	0.950

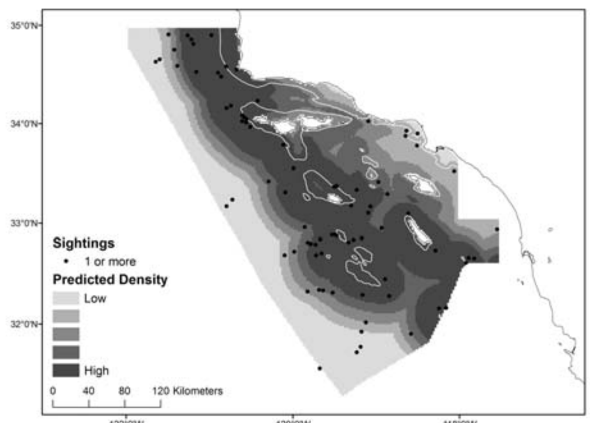
Values of interpolated oceanographic and bathymetry variables were extracted at the midpoints of a 2km x 2km grid of the study area and used as input to the final models to predict the number of whales. Whale density in each cell was calculated by dividing the predicted number of whales by 2*effort*ESW*g(0), where effort was assumed to be 1km and the effective strip width (ESW, 1.715 for fin and blue whales, and 2.894 for humpback whales) and g(0) (0.90 for all species) were taken from Barlow (2003). Maps summarizing whale densities in all years (Fig. 3) were created by taking a weighted average of the density predicted in each cell for each year, where the weights were the proportion of survey effort in the study area for that year.

Figure 3. Maps of predicted density are shown for fin, blue, and humpback whales. Sightings are shown as black dots; the 200m isobath is shown as a white line. The density categories are not the same in each map, but represent low to high densities unique to each species.

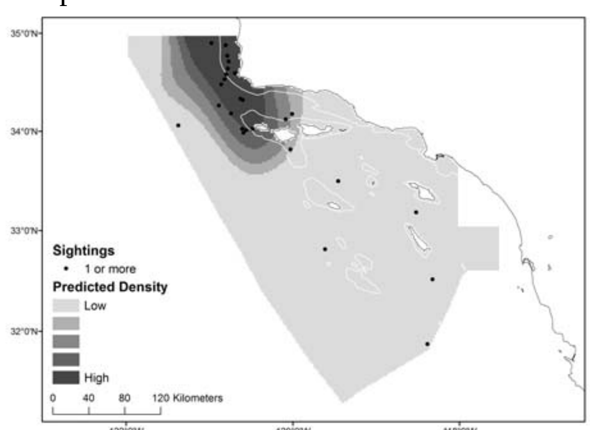
Fin whales



Blue whales

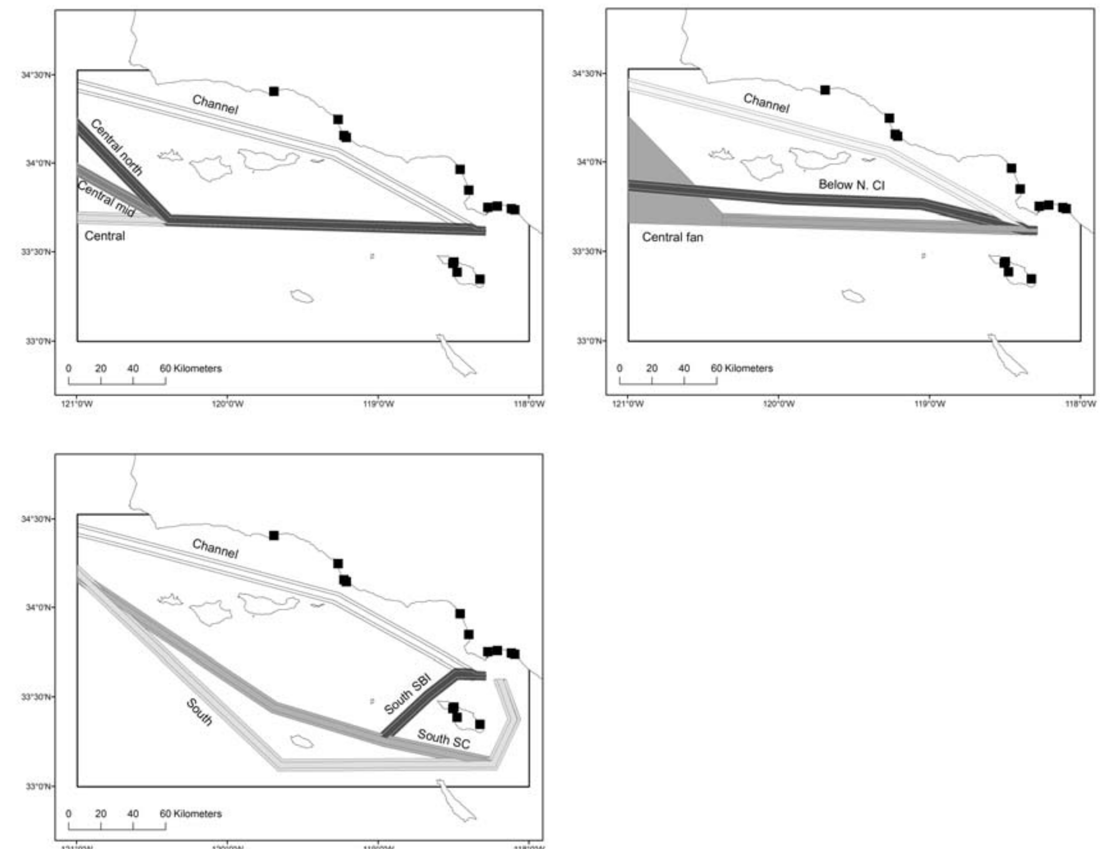


Humpback whales



All of our traffic separation scheme (TSS) options were comprised of an inbound lane, an outbound lane, and a middle traffic separation area; for all routes, we assumed that no ships travelled in the middle traffic separation area. All of our TSS options were based on discussions with the U.S. Coast Guard about routes considered for the Port Access Routing Study (PARS) being conducted for the Southern California Bight. The route labeled “Channel” represents the status quo (Fig. 4). The routes labeled “Central north”, “Central mid”, and “Central” (Fig. 4) represent different options for establishing a TSS south of the northern Channel Islands. The route labeled “Central fan” (Fig. 4) represents the option of establishing a shorter TSS in this region. For this route, we assumed lower ship density outside of the TSS (i.e., in the fan), because ships could take a variety of approaches to the TSS. Ship density in the fan was calculated as the ratio of the area in the Central TSS that occurred in the fan to the area of the fan. The boundaries of the fan were derived from vessel traffic patterns observed in Automatic Identification System (AIS) data (McKenna et al. in prep.). The route labeled “Below N. CI” (Fig. 4) represents a more northern option for a TSS south of the northern Channel Islands. Finally, we considered three southern routes (i.e., South, South SC, and South SBI in Figure 4). These routes were derived from vessel traffic patterns observed in AIS data (McKenna et al. in prep.).

Figure 4. Alternative shipping routes considered in the Southern California Bight.

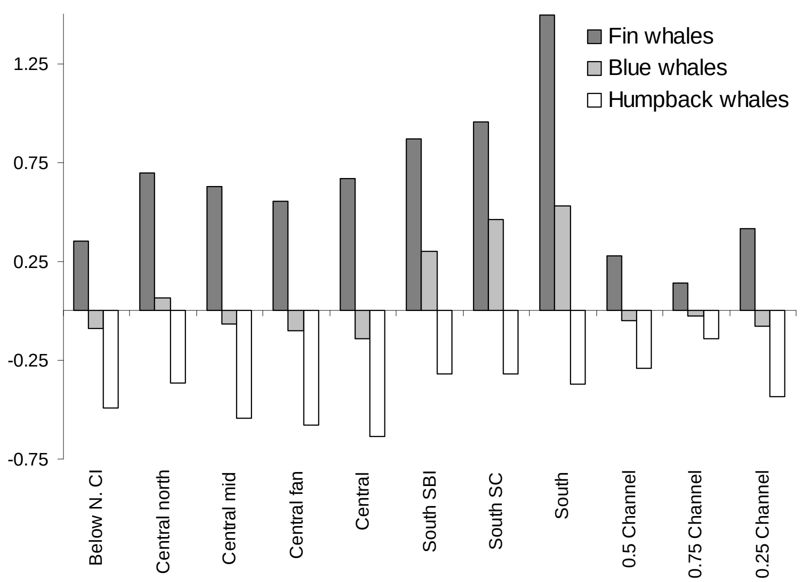


Risk was calculated as the sum of the predicted number of whales within the inbound and outbound lane in each TSS. For the Central fan TSS, the number of whales in the fan was multiplied by ship density to account for the lower ship density expected in the fan. The resolution of the predicted whale densities is too coarse to evaluate small scale changes in individual TSS options (e.g., decreasing the distance between the inbound and outbound lanes in the Channel TSS), but can be used to evaluate differences in risk among the TSS options. Results are summarized as the percentage change in risk for each TSS option relative to the status quo of the Channel TSS (Fig. 5):

$$\text{Percent change} = \frac{(\text{Risk in TSS} - \text{Risk in Channel})}{\text{Risk in Channel}}$$

Additionally, we calculated the percentage change in risk for three options comprised of varying levels of traffic in the Channel TSS versus the central fan TSS (25% versus 75%, 50% in both, and 75% versus 25%), to mimic a situation in which two TSS options exist.

Figure 5. The percentage change in risk for each TSS option relative to the status quo of the Channel TSS is shown for each species; negative values suggest that the Channel has higher risk than the TSS option being considered.



The risk for fin whales increases whenever ships occur in TSS options other than the Channel and is highest in the farthest south TSS. For fin whales the best option is to leave all, or at least some, traffic in the Channel or to use the Below N. CI TSS. The risk for humpback whales decreases whenever ships occur in TSS options other than the Channel. However, the decrease in risk is not as large for the southern TSS options, due primarily to their increased length. The predicted density hot spot for blue whales traverses the study area, resulting in more complicated patterns of risk among the TSS options and generally smaller values of the percentage change in risk than was observed for the other species. In general, small decreases in risk were observed when ships occurred in the central TSS options rather than the Channel TSS, but increased when ships occurred too far south.

Although we have analyzed three scenarios in which traffic was shared between the Channel and Central fan TSS options, in practice the number of ships using each TSS cannot be controlled when multiple TSS options exist. If we consider the establishment of a single TSS, the TSS that occurs just south of the northern Channel Islands appears to minimize the risk for all species. Specifically, it produces the smallest increase in risk for fin whales while still decreasing the risk for blue and humpback whales. However, we need to determine how to weight these species when making a recommendation about the best TSS option in this region. For example, the average number of fin whales contained in all TSS options was 10.2 (range: 6.4 to 16.0), while the average number of blue whales was 6.3 (range: 5.1 to 9.0) and the average number of humpback whales was 2.3 (range: 1.3 to 3.6). Consequently, we need to consider whether the higher risk for fin whales gives them higher priority in selecting an optimal TSS option. This consideration of risk magnitude needs to be balanced against the status of each species in this region.

References

Barlow J (2003) Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991-2001. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, Administrative report LJ-03-03, La Jolla, CA

Barlow J, Ferguson MC, Becker EA, Redfern JV, Forney KA, Vilchis IL, Fiedler PC, Gerrodette T, Ballance. LT (2009) Predictive modeling of cetacean densities in the eastern Pacific Ocean. NOAA Technical Memorandum NMFS-SWFSC-444. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA, pp 206

Barlow J, Forney KA (2007) Abundance and density of cetaceans in the California Current Ecosystem. Fishery Bulletin 105: 509-526

Becker EA, Forney KA, Ferguson MC, Foley DG, Smith RC, Barlow J, Redfern JV (2010) Comparing California Current cetacean-habitat models developed using in situ and remotely sensed sea surface temperature data. Marine Ecology Progress Series 413: 163-183

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to Distance Sampling: Estimating abundance of biological populations. Oxford University Press, Oxford

Ferguson MC, Barlow J, Fiedler P, Reilly SB, Gerrodette T (2006) Spatial models of delphinid (family Delphinidae) encounter rate and group size in the eastern tropical Pacific Ocean. Ecological Modelling 193: 645-662

Forney KA (2000) Environmental models of cetacean abundance: reducing uncertainty in population trends. Conservation Biology 14: 1271-1286

Hastie TJ, Tibshirani RJ (1990) Generalized Additive Models. Chapman & Hall/CRC, Boca Raton

Kinzey D, Olson P, Gerrodette T (2000) Marine mammal data collection procedures on research ship line-transect surveys by the Southwest Fisheries Science Center. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, Administrative Report LJ-00-08, La Jolla, CA

McKenna MF, Ross D, Wiggins SM, Hildebrand JA, Katz SL, Moore TJ, Redfern JV (in prep.) Quieter Ocean: Unintended Consequence of Recent Ship Traffic Trends